Anticipated results from the EOS Terra Multi-angle Imaging SpectroRadiometer

MISR

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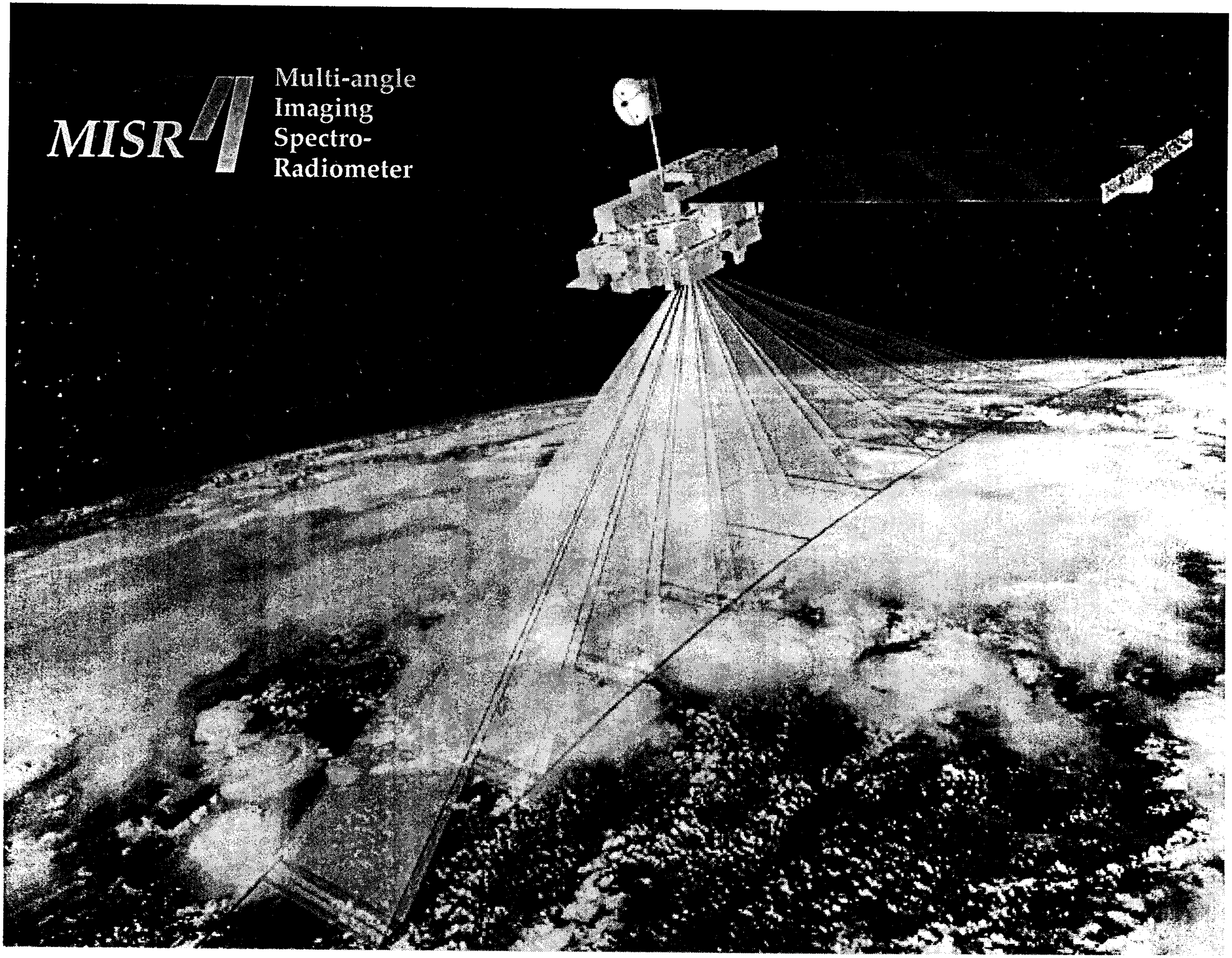

MISR
Multi-angle
Imaging
Spectro-
Radiometer

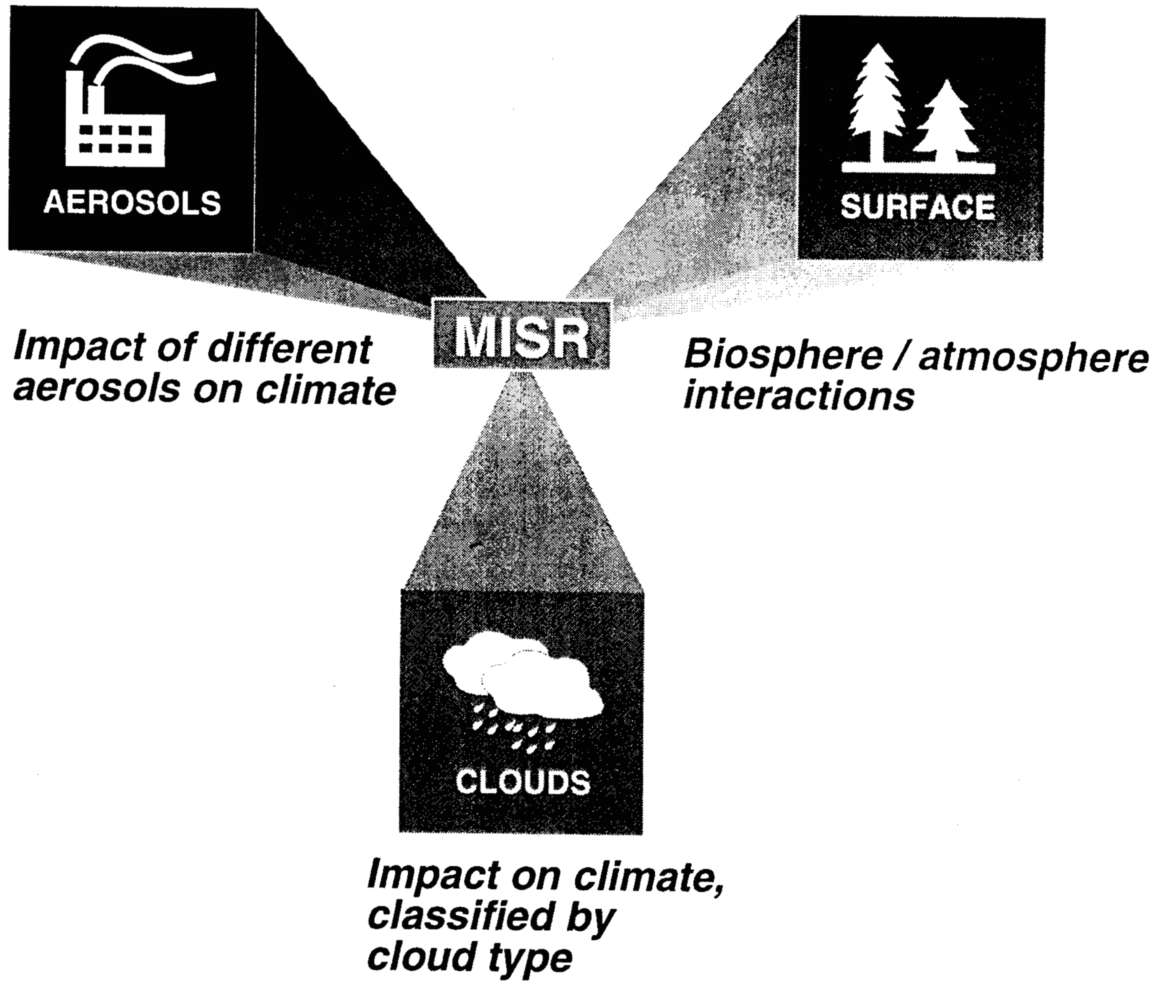
WHY TAKE MULTI-ANGLE IMAGES?

Sunlight drives the Earth's climate system and natural objects reflect and scatter sunlight diffusely--into all directions

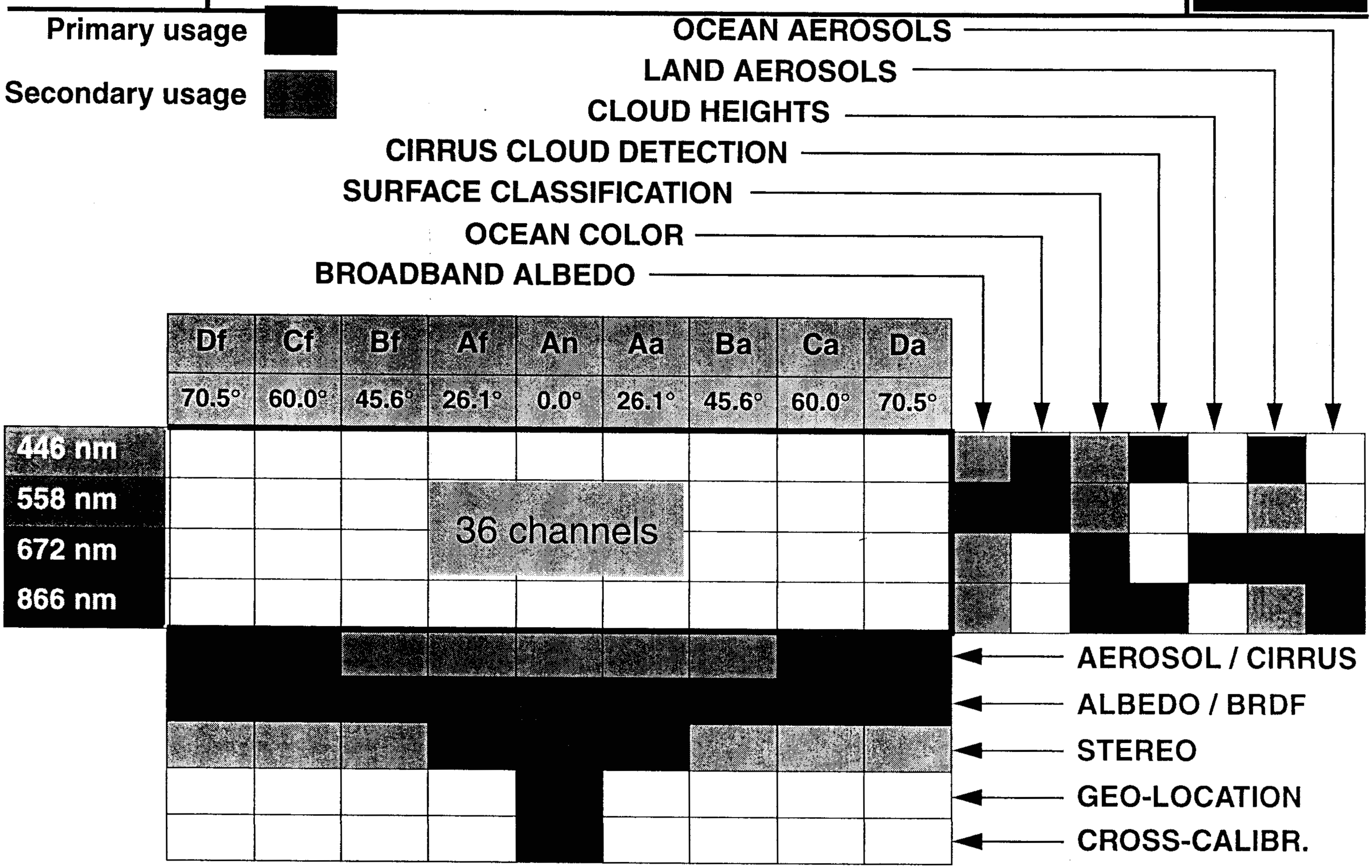
The amount of energy absorbed and reflected are fundamental climate parameters

Accurate retrievals of geophysical quantities (e.g., aerosol optical depth, cloud albedo, vegetation productivity) require physical scene classification

Multi-angle images provide such information, e.g.,
--aerosol type
--cloud height and morphology
--biome type



SCIENCE RATIONALE FOR NINE CAMERAS / FOUR BANDS



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MISR Key Science Questions: *Clouds*

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How do spatial and seasonal variations of different cloud types affect the planetary solar radiation budget? To what degree can clouds act to amplify or dampen the Earth's response to global warming due to greenhouse gases?

- *Regional studies of the role of clouds in radiation require measurements of radiation budgets as a function of scene type*
- *Coarse-resolution across-track scanners do not see the same region from different directions, rely heavily on scene identification algorithms to construct statistical populations, and can incur biases due to increasing target area with angle*
- *Nadir imagers cannot always detect cirrus clouds due to restricted phase angle coverage; must combine data from many geographic locations to generate BRDFs*

MISR will provide:

- Scene-dependent anisotropic reflectance models and spectral radiative forcing
- Direct integration of multi-angle reflectances to obtain high spatial resolution spectral albedos with global coverage
- Validation of coarse resolution products from other sensors (CERES)
- Cloud elevations using stereo-imagery
- Parameterizations of cloud-radiative effects for GCMs

MISR Key Science Questions: *Aerosols*

Is there a detectable trend in global aerosol loading, and if so, what are the anticipated climatic and environmental consequences?

- *Human activities such as fossil fuel burning, slash-and-burn agriculture, and deforestation can lead to changes in the abundance and composition of tropospheric aerosols*
- *Changes in aerosol burden can have significant climatic effects, either directly, or by causing changes to cloud properties*
- *Net radiative effect of aerosols (i.e., whether they heat or cool the surface) depends on optical properties and albedo of underlying surface. Effect is regionally variable due to heterogeneity of land surface and spatial variability in aerosol types*
- *Global aerosol burden and net effect on energy budget is currently undetermined*

MISR will provide determinations of:

- Aerosol optical properties and abundances over land and ocean, routinely
- Regional and global trends
- Aerosol forcing on shortwave radiative energy budgets
- Cloud albedos in pristine and polluted environments

JPL | MISR Key Science Questions: *Land Surface* | MISR

What are the climatic implications of natural and human-induced modifications to the structure, distribution, and extent of the Earth's forests, deserts, and cryosphere? How widespread are the effects of human activities, and how rapidly are changes occuring?

- *Terrestrial surfaces are not lambertian and hemispherical albedos cannot be inferred from nadir reflectances*
- *Structural information cannot be retrieved from nadir spectral data alone*

MISR will provide, routinely and globally:

- Bidirectional reflectance distributions (which are governed by surface optical properties and geometry) for soils, snow, ice, and vegetated surfaces, which will be used to improve radiative boundary conditions of climate models
- Improved surface cover classification using angular signature information
- Land surface topography at moderate resolution

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MISR Key Science Questions: *Biosphere-Atmosphere Interactions*

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What are the present fluxes of energy and mass (CO_2 and H_2O) across the vegetation-atmosphere interface? What is the impact of land surface processes on climate variables such as rainfall patterns?

- *Explicit inclusion of a vegetation radiative transfer and evapotranspiration model in a GCM led to better agreement between calculated and observed energy and rainfall fluxes (Sellers et al., 1986; Sato et al., 1989)*
- *Realistic modeling of energy (radiation, heat) and mass (water, carbon dioxide) transfer between the biosphere and atmosphere requires determination of canopy structure and absorbed photosynthetically active radiation (APAR)*

MISR will provide, routinely and globally:

- Surface hemispherical albedos in the visible and near-IR, which are needed for estimating surface energy balance and evaporation rates, vegetation canopy APAR, and canopy photosynthesis and transpiration rates

UNIQUE MEASUREMENTS PROVIDED BY MISR

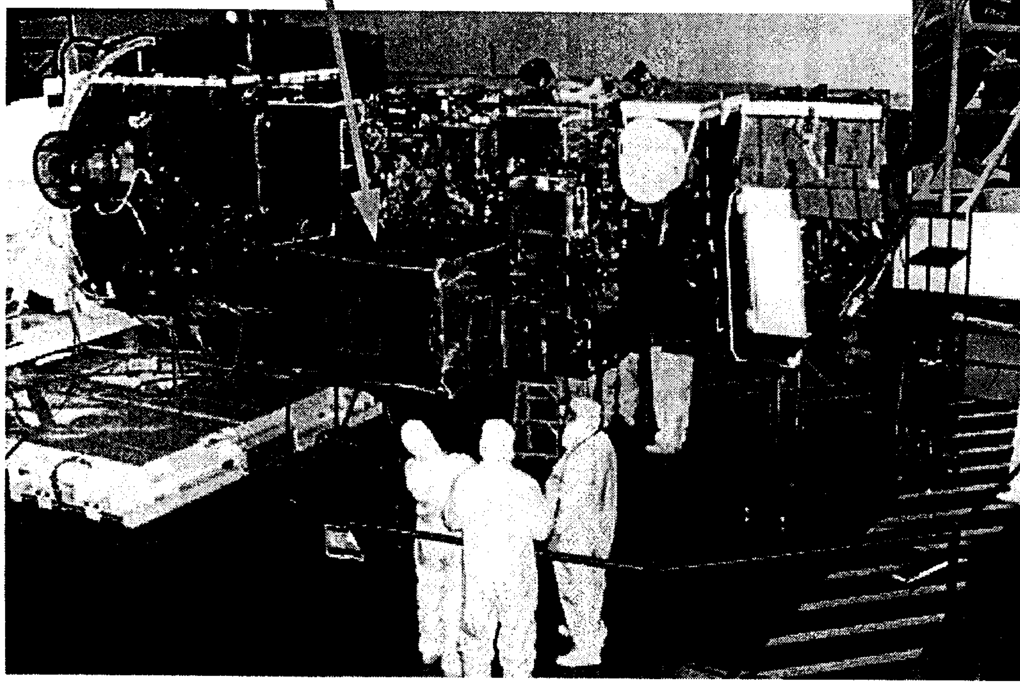
Unique measurement	Comment
Top-of-atmosphere, cloud, and surface anisotropic reflectance	Needed for determining albedo and understanding how target geometry governs radiative properties. MISR is the only instrument capable of providing such data with *all* of these attributes: • routine acquisition, within short time intervals for individual scenes • global coverage • sufficient spatial resolution to provide unambiguous scene identification and to minimize non-linear effects associated with scene heterogeneity • very high off-nadir view angles, both fore and aft
Aerosol burden, optical properties, and shortwave radiative forcing over land	Needed for studies of aerosol sources, trends, climatic effects, and atmospheric corrections. MISR uses multi-angle information to separate out surface from atmosphere, and: • is the only instrument with dedicated multi-angle imagery to monitor aerosols routinely over land • enables aerosol retrievals over a much wider range of land surface and atmospheric conditions than possible with nadir imagers

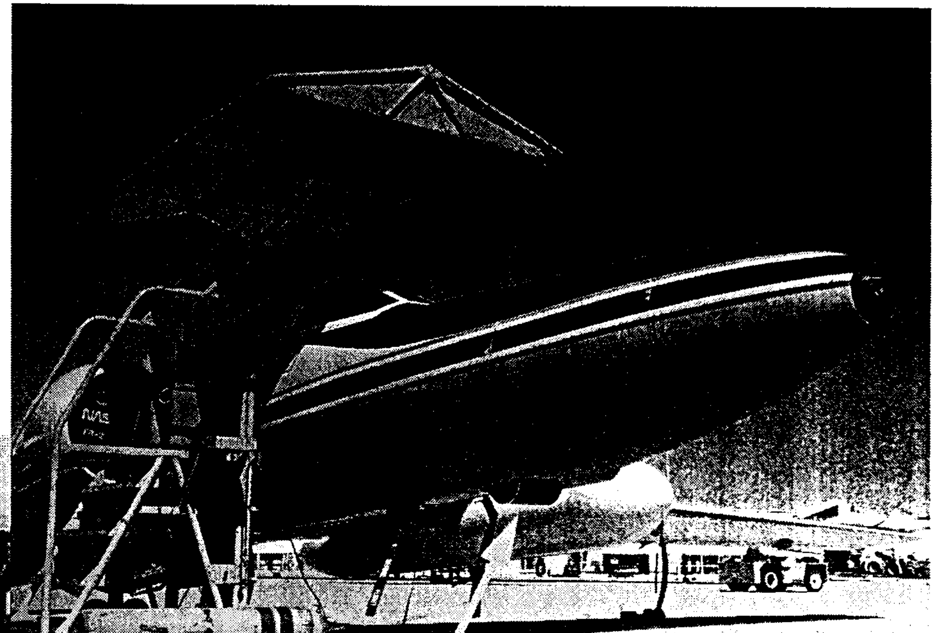
UNIQUE MEASUREMENTS PROVIDED BY MISR (CONTINUED)

Unique measurement	Comment
Scattering phase functions of aerosols and cirrus clouds	Needed to determine whether net radiative effect is cooling or heating, and to improve and validate aerosol retrievals over ocean. MISR provides direct observations over a wide range of phase angles and offers the only way to observe geographic variations in cirrus scattering properties globally and consistently
Surface spectral albedo	Needed to determine: • shortwave radiative fluxes, feedbacks between surface (biosphere, cryosphere) and atmosphere • mass fluxes between terrestrial vegetation and the atmosphere Can only be determined accurately with multi-angle observations and simultaneous atmospheric correction. MISR provides the required data routinely, globally, and with high spatial and temporal resolution, particularly in the climatically important ice- and snow-covered polar regions
Surface and cloud elevations	Needed for geomorphologic studies, topographic corrections, and cloud identification. Provided using MISR's stereoimaging capability

MISR AND AirMISR INSTRUMENTS

MISR on Terra spacecraft



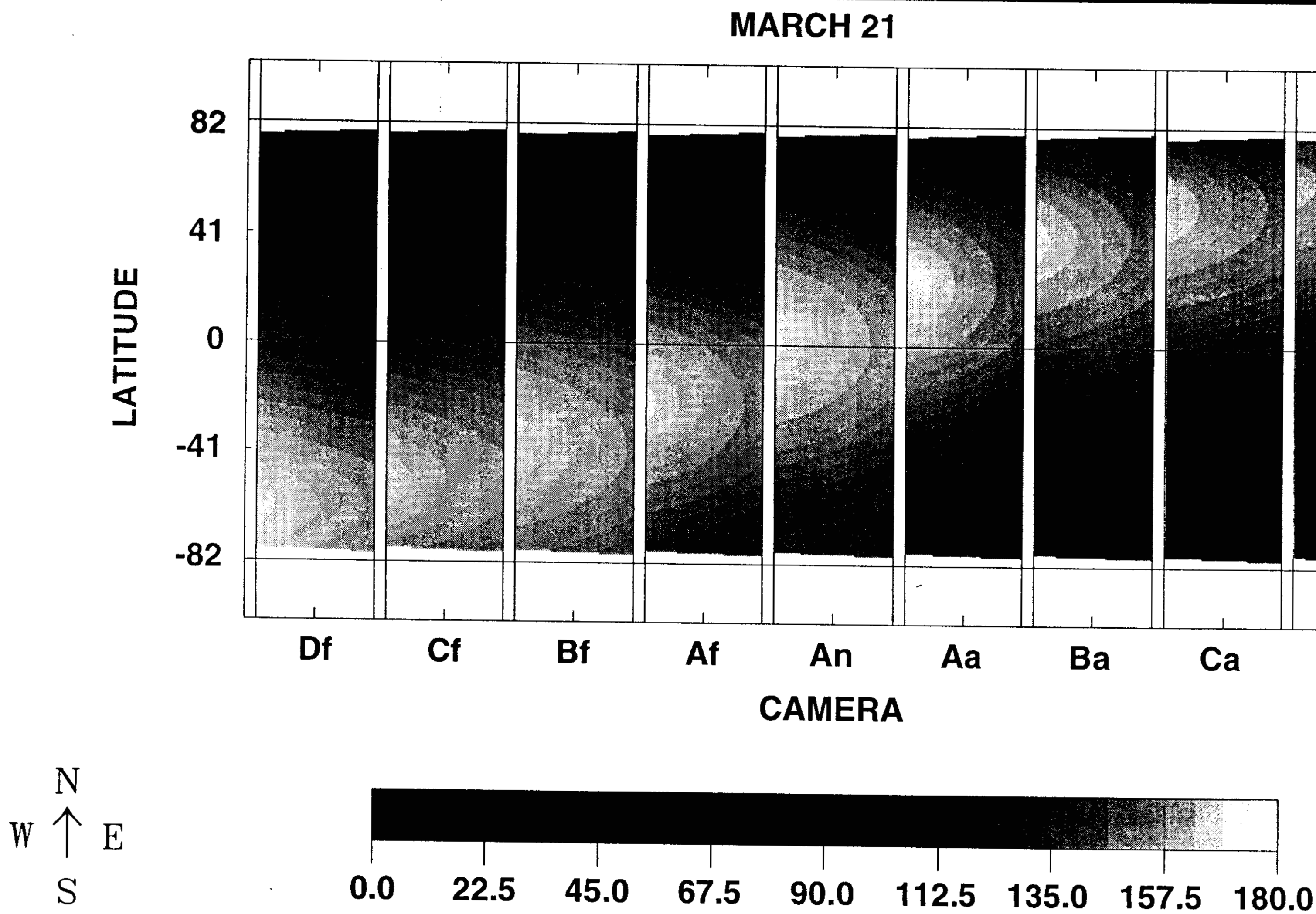


AirMISR on NASA ER-2 aircraft

OBSERVATIONAL PARAMETERS

Parameter	MISR	AirMISR
Number of cameras	9	1 (gimballed)
View angles	0.0°, 26.1°, 45.6°, 60.0°, 70.5° (fore and aft)	Same
Spectral bands	446, 558, 672, 866 nm	Same
Ground sampling (georectified images)	275 m - 1.1 km	27.5 m
Swath width	360 km (9 day global coverage)	11 km
Time to observe single target	7 minutes	13 minutes
Azimuths relative to principal plane	From EOS-AM orbit 30° - 90°, depends on latitude/season	Selectable flight lines
Radiometric calibration	On-board and vicarious ± 3% at full signal	Laboratory and vicarious ± 3% at full signal
Signal-to-noise ratio	> 700 at full signal	Same
Quantization	14 bits	Same

MISR SCATTERING ANGLE COVERAGE



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MISR DATA PROCESSING FLOW

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Reformatting / Annotation Subsystem
Level 1A

- Raw data ingest
- Data reformatting
- Data annotation

Radiometric / Geometric Subsystems
Level 1B

- Radiance scaling
- Radiance conditioning
- Geometric rectification and registration
- Cloud detection

Top-of-Atmosphere / Cloud Subsystem
Level 2

- Reflecting level parameter generation
- Cloud classification
- TOA albedo calculation

Aerosol / Surface Subsystem
Level 2

- Retrieval path determination
- Aerosol retrieval
- Surface retrieval

Gridding / Binning Subsystem
Level 3

- High-level parameter generation
- Global gridding
- Temporal binning

Research / Modeling Subsystem
Level 4

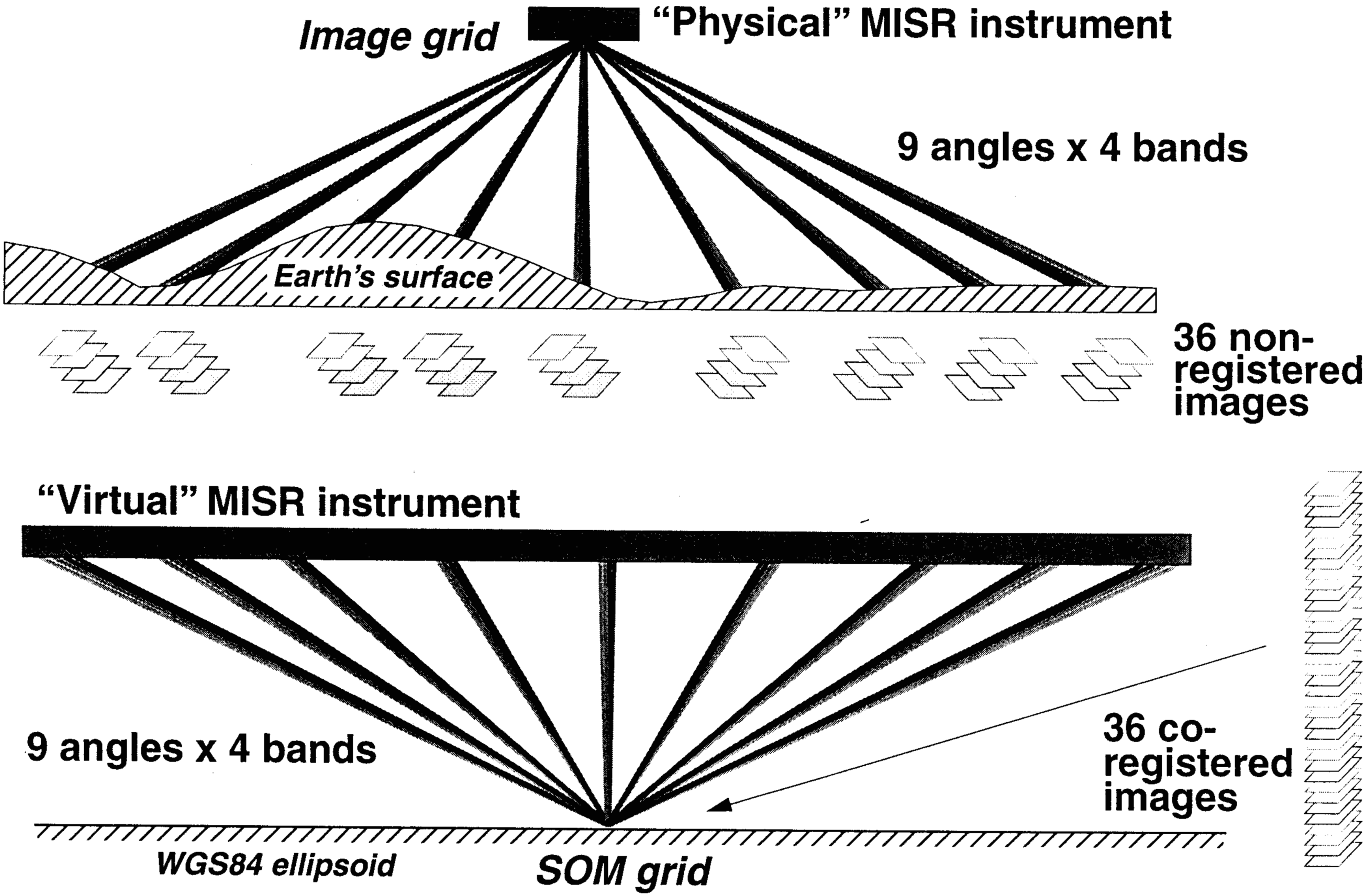
- Model generation
- Data analysis
- Research publication

Validation

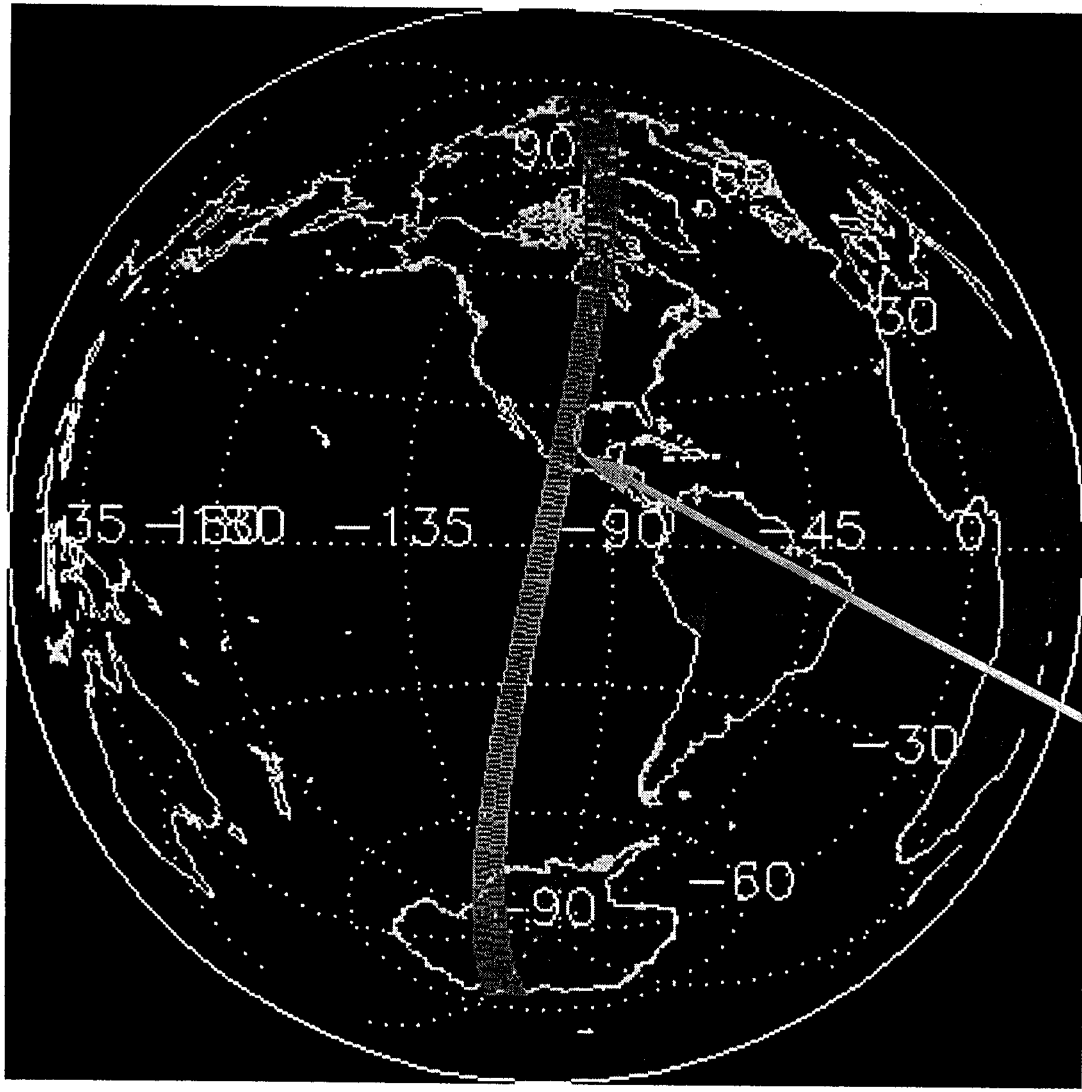
and

Quality Assessment

SOM PROJECTION PROVIDES REQUIRED CO-REGISTRATION



SPACE OBLIQUE MERCATOR PROJECTION



World Reference System Path 27

Location of simulated MISR data

MISR LEVEL 2 ATMOSPHERE PRODUCTS

Product	Process	BRDF Model
Reflecting level (cloud or surface) altitude	Multi-angle stereoscopic retrieval	None
Aerosol optical depth and compositional type	Aerosol retrieval over dark ocean, dense dark vegetation (DDV), or heterogeneous land	Heterogeneous land: Empirical Orthogonal Function angular expansion DDV: Rahman-Pinty-Verstraete (3 parameter) empirical BRF model Ocean: Cox-Munk glitter + whitecaps
Top-of-atmosphere BRFs and albedos	Geometric registration of multi-angle data to reflecting level altitude, and angular integration	Clear sky: Linearized form of Rahman-Pinty-Verstraete model Cloudy sky: Physically based Monte-Carlo radiative transfer models

Increasing BRDF model complexity

BRF - Bidirectional Reflectance Factor

MISR LEVEL 2 SURFACE PRODUCTS

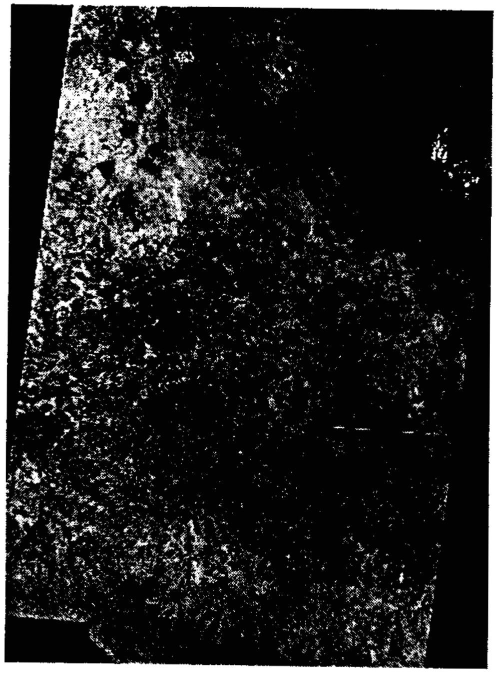
Product	Process	BRDF Model
Spectral HDRFs and BHR	Requires aerosol retrieval and atmospheric correction of multi-angle measurements	Surface-leaving radiance form: $L(\mu, \phi - \phi_0) = L_0(\mu) + L_1(\mu)\cos(\phi - \phi_0)$
Spectral BRFs, DHR, and BRF model parameters	Inversion of multi-angle HDRFs using a multi-parameter BRF model	Linearized form of Rahman-Pinty-Verstraete model
Biome type, LAI, and FPAR	Spectral BRFs and BHR/DHR compared to values for various canopy/soil models in a look-up table (LUT)	3-D radiative transfer and physically-based canopy models

Increasing BRDF model complexity

HDRF - Hemispherical-Directional Reflectance Factor (proportional to surface-leaving radiance)
BHR - Bihemispherical Reflectance (albedo under ambient illumination)

BRF - Bidirectional Reflectance Factor
DHR - Directional-Hemispherical Reflectance (albedo under direct illumination only)

STEREOSCOPIC RETRIEVALS IN MISR TOA/CLOUD PROCESSING



RADIANCE IMAGE

HEIGHT FIELD

RETRIEVED REFLECTING-LEVEL REFERENCE ALTITUDE

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AirMISR
ANGULAR REFLECTANCES

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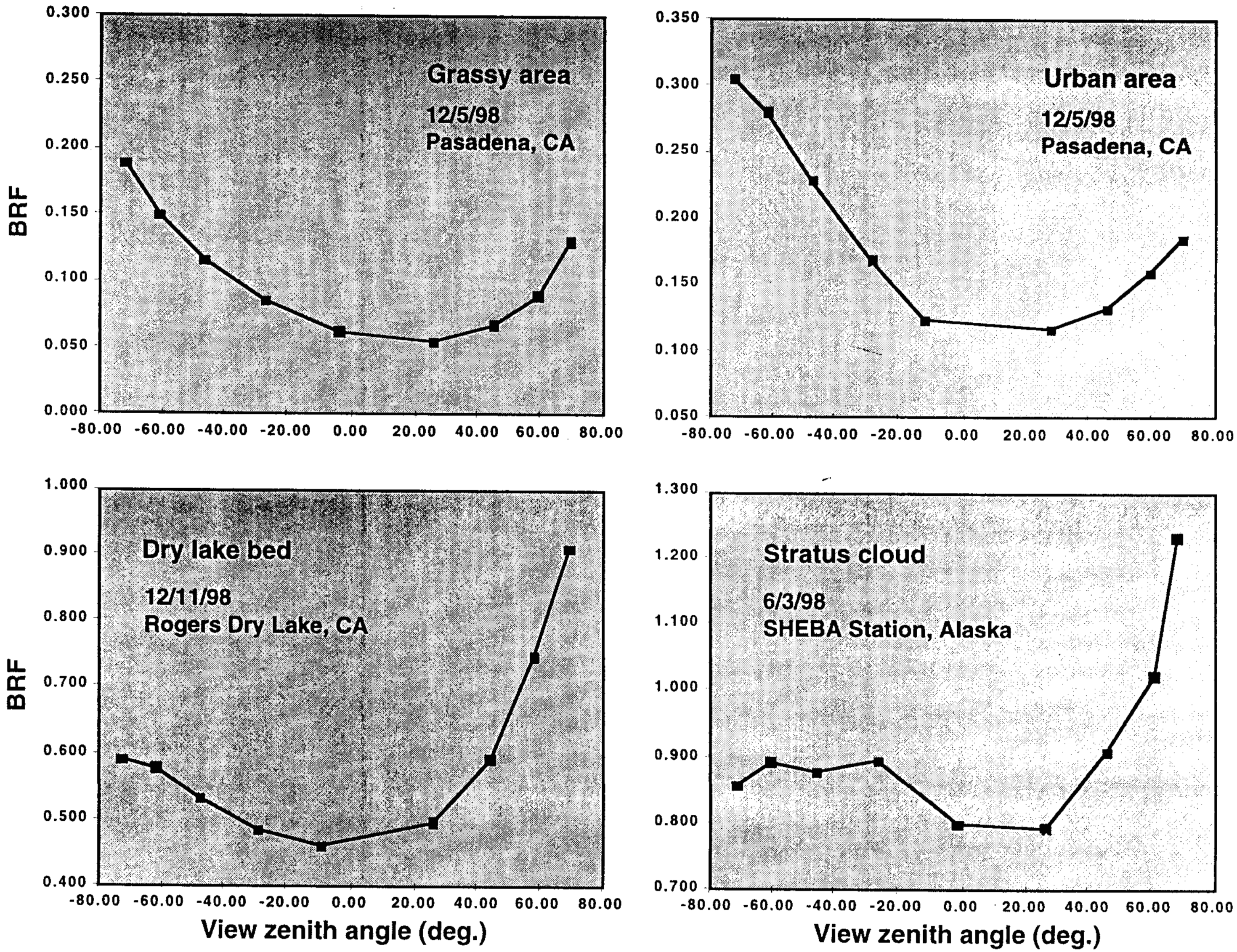

MISR LEVEL 3
GLOBALLY-GRIDDED PRODUCTS

1° x 1° equi-angle grid
Generated monthly

Statistical summaries of Level 2 products
- Means, covariances, and frequencies

Component products:
- Global Aerosol Product
- Global Land Surface Product
- Global Reflecting Level Product
- Global Cloud Classification Product
- Global Albedo Product

Joint products:
- Global Climate Product

LEVEL 3 COMPONENT PRODUCTS

Global Aerosol Product
Overall best estimate optical depth
Model class optical depths and retrieval fit measures (clean, industrial, biomass burning, and dusty--continental and maritime)

Global Land Surface Product
Bidirectional reflectance analytical model parameters
Biome type histogram (frequency of barren, water, grasses and cereal crops, shrublands, broadleaf crops, savanna, broadleaf forest, needle forest)
Directional hemispherical reflectance (albedo): spectral and PAR-integrated
Leaf Area Index and Fractional Absorbed Photosynthetically Active Radiation

Global Reflecting Level Product
Reflecting Level Reference Altitude (derived stereoscopically)

LEVEL 3 COMPONENT PRODUCTS (CONTINUED)

Global Cloud Classification Product
Land and water fractions
Altitude-binned clear/cloud fractions

Global Albedo Product
Scene classifiers (cloudy/clear, surface type, high cloud presence, cloud phase, cloud altitude, cloud texture)
Top-of-atmosphere spectral albedo
Bidirectional Reflectance Factors at MISR's 9 angles, red band

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LEVEL 3 JOINT PRODUCT

MISR

Global Climate Product
Best estimate aerosol optical depth
Top-of-atmosphere spectral albedo
Cloudy/clear scene classifier
Biome type/ocean scene classifier
Reflecting level reference altitude
Fractional absorbed photosynthetically active radiation
Normalized difference vegetation index
Leaf area index